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DIASTROPHISM AND THE FORMATIVE PROCESSES. VI

FORESET BEDS AND SLOPE DEPOSITS

T. C. CHAMBERLIN
University of Chicago

Nearly all marine sediments are carried to their resting-places in one or another of three general ways: (1) by rolling or sliding down relatively steep slopes, where gravity is the chief factor and the agitation of the water only an auxiliary agency; (2) by being forced along low slopes where agitation and currents are essential factors; and (3) by flotation, where the relative levity or fineness of the material is an essential factor. These are conveniently called (1) foreset beds, (2) topset beds, and (3) flotation beds. If we may use these terms in a rather free and broad sense, based on the dominant feature, with neglect of intergradations and alternations, it will be convenient to speak of the shelf-sea deposits as topset beds, of the deposits of the abysmal slope as foreset beds, and of the deep-sea deposits as flotation or bottom-set beds, though flotation contributions enter in notable measure into the composition of both the other classes.

The abysmal deposits were the subject of our last discussion, and in earlier articles the shelf-sea deposits were under study. It remains to see, so far as we may, what bearings on diastrophic problems the foreset beds have, taking as our leading type those that lie on the abysmal faces of the continental terraces.

These foreset beds are formed of a coarser and a finer element. The coarser embraces material that has been rolled or pushed by stages over the upper face of the continental shelves until the oceanward edges of these were reached, beyond which the material has descended the steeper slopes under degrees of agitation of milder sorts than those required to move them over the upper face of the shelves. These materials may be said to be the overflow of the topset or shelf-sea beds. As these slope deposits are gradually built out, they serve as a causeway on which the topset beds are advanced seaward.

The finer element embraces those portions of the silts from the land that were light enough or fine enough to be kept in suspension—or to be stirred up frequently into temporary suspension—by the agitated waters of the shelf-seas and so borne oceanward continuously or by stages. They were, however, insufficiently comminuted to float long and so to reach the central ocean areas and find lodgment in the true abysmal depths. This element in general is intermediate between the coarser flotation material which settles and remains on the sea-shelves in spite of considerable agitation, and the extremely fine silt that reaches the heart of the ocean and enters into the deep-sea deposits.

The many obvious qualifications of these broad statements need not detain us here for we are seeking chiefly the relations of these formative processes to problems of diastrophism. The matter of first special interest in this relationship concerns the thicknesses of the foreset, the topset, and the flotation beds respectively and the inferences drawn from these thicknesses. It is common practice to regard the thickness attained by any series of beds prior to a deformation, as a measure of the subsidence of the crust, if evidences of agitated water or shoal life occur at various horizons in the series. This inferred subsidence, when large, is often thought to have invited a deformative movement. Theories of the cause or of the localizing agency of deformations have been hung on such supposed proof of deep subsidence. Appeals have been made to a rise of the geotherms supposed to be consequent upon subsidence. Even softening or melting of the under crust has been deduced from such depression. When the series is thick and shows abundant evidence of shallow-water action at nearly all horizons, these features have been regarded as proof of such deep subsidence, and the proof has been felt to be quite irrefragable. Few tenets of geology have a firmer hold on the convictions of working geologists or have seemed more nearly axiomatic. If the trustworthiness of this tenet is to be called in question, in any sense, or in any degree, the grounds for so doing should be clear.

Flotation beds may be laid down in strict horizontality, and on slopes of various moderate degrees as well. Sediments that come into place only by sliding or rolling usually require a declining gradient. It is admissible to regard the abysmal beds, looked at broadly, as essentially horizontal. Additions to them are made by sheets of flotation sediment falling from above with some approximation to uniformity. The thicknesses that may be attained by such beds in the ocean, so long as the crust maintains a static condition, are strictly limited by the depth of the ocean. This seems a mere truism and falls in with the instinctive inferences that have given rise to the common conviction.

It is, however, admissible, if not imperative, to regard the sea-shelves as sloping from the continents oceanward, and to recognize that in the very nature of their formation, they persist in sloping systematically toward the ocean at all stages of their formation when they are built up normally. The slopes on the present continental shelves vary through a considerable range. The precise slope is not a matter of special moment in this paper, though it is important in special problems. It will serve our present purpose to recognize slopes as being often as low as three feet per mile and often as high as twelve feet per mile, or from 1 in 1,760 to 1 in 440, while both lower and higher slopes are not uncommonly observed. For this discussion let us take the conservative figure of four feet per mile, or 1 in 1,320, as representative. While it is not here important to assume one approximate figure rather than another, it is important to recognize that some such slope is a systematic feature of the shelf-sea deposits in their normal state, that it is inherent in the nature of the case, and that it may safely be presumed to have affected the sea-shelf deposits of all periods.

At the oceanward edge of these slightly sloping shelves, the topset beds join at an angle or curve the foreset beds that form the steeper abysmal slope. While the dips of the foreset beds have large variations, they are usually much higher than the topset beds and this higher dip is a systematic feature. Such higher dips must be presumed to have affected the foreset beds in all stages of shelf growth and to be a persistent feature. Willis generalizes the commoner angles of the present abysmal slopes at 2° to 5°, which may be translated, roundly, into 1 in 30 to 1 in 12, but much higher and much lower slopes occur. These slopes vary with conditions, as in the case of the topset beds, but, in the nature of the case, they persist at some grade so long as there is continental feeding and effective shelf-sea action.

If now the picture of the slopes of the topset and of the foreset beds of the continental shelves, and their relations to one another, are clearly in mind, and it is plainly seen that they are persistent and systematic features, we are prepared for the question: What is the limit of thickness of foreset and topset beds in an ocean of given depth where no subsidence or creep takes place? As thus stated, no determinate answer to the question is possible. The depth of the ocean—beyond a sufficient working depth—is essentially immaterial so far as the theoretical possibilities of thickness are concerned. It is rather the *breadth* of the ocean than its *depth* that controls the possible thickness of such sloping beds. *The growth of the continental shelves oceanward increases the thickness of the topset and foreset strata irrespective of the ocean depth.* The ocean depth merely determines the amount of material required to effect the oceanward growth. While it may thus influence the rate of growth in thickness or the ratio of topset beds to foreset beds, or their slopes, or other details incidental to thickness, it is not vital to the possibilities of thickness.

If all this is not evident from the mere statement of the case, it should become so from an inspection of the accompanying figure in which it is assumed that the crust remains absolutely stationary, that there is a continual supply of material from the land, that the sea surface changes only as it is forced to rise by sea-filling, that the depth of effective shelf-sea action is 100 fathoms, and that a normal distribution of sediment arises from the movements of the sea-water. According to standard methods of finding the thickness of beds, the measurement is taken on lines normal to the deposition planes. This is obviously the correct method, as it sums up the successive increments of sedimentation. It will be seen from the diagram (Fig. 1) that the topset and the foreset beds increase by the addition of layer laid obliquely upon layer in the course of the growth seaward and that these lie in essentially the same horizon and may accumulate quite irrespective of the total depth of ocean.

A growth of the continental shelf seaward to the extent of 1,000 miles would increase the sum of the thicknesses of the topset or sea-shelf strata to the amount of 4,000 feet, if the shelf slope were constant at 1 in 1,320; while the sum of the foreset beds on the abysmal slope would increase to 176,000 feet, if its inclination remained constant at 1 in 30, i.e., constant at a slope of about 2°. The thicknesses of topset beds under the range of slope given above would vary from 3,000 feet to 12,000 feet and of foreset beds from 176,000 feet to 440,000 feet. In all this, it is assumed that there is absolutely no subsidence of the crust, nor creep, nor diastrophism of any kind, nor any change of any kind, except what may be involved in keeping up a supply of terriginous matter and in maintaining normal sea action on the shelf, and so maintaining a systematic growth seaward.

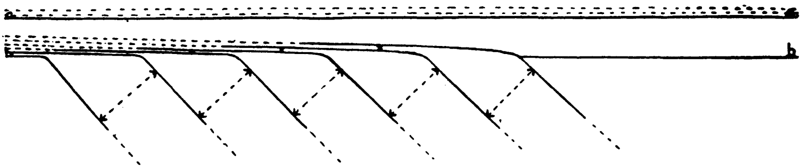

FIG. 1.—*aa*, sea level; *bb*, limit in depth of effective surface action; crust stationary; creep absent; silt supply constant; action strictly normal; slopes exaggerated.

From this it is easy to see that, given a sufficient supply of material and a continuance of normal action and static condition, it would be possible for normal processes to build out into the ocean a series of foreset beds that would sum up a thickness much exceeding the whole geological column, without the slightest subsidence. Even the sea-shelf beds in such a case would attain a very impressive sum of thicknesses.

In these statements, it is assumed that thicknesses are measured in the standard way, bed by bed, at right angles to the bedding planes.

Under the perfectly stable conditions named, and on the assumption that the angle between the topset and foreset beds of the continental shelf was maintained at 100 fathoms below the sea surface, the series of shelf-sea deposits would never have a vertical depth of more than 600 feet plus the rise of the sea-level due to filling, but, *because they lie inclined upon one another*, the sum of their individual thicknesses may have reached the impressive figures indicated. So also, under these conditions, the vertical depth of the foreset beds would never equal the depth of the ocean, but the sum of their individual thicknesses might many times exceed its greatest depth.

Under the conditions named, the shelf-sea or topset deposits should bear abundant evidence of a shallow water origin at all horizons, since none were formed at a greater depth than 600 feet, plus the rise of the sea-level, and yet their stratigraphic thickness measured in the usual way, the correct way, might rise to some thousands of feet without the slightest subsidence.

Under the same conditions, the upper edges of the foreset beds, or beds of the abysmal slope, might show evidences of sea agitation and the special marks of currents actuated by winds and tides, and they might be filled with fossils that lived within a thousand feet or so of the sea surface. These evidences of somewhat shallow water might affect the upper edges of tens of thousands or hundreds of thousands of feet of inclined beds measured in the usual correct way. Farther down on the abysmal slope the beds would of course carry life implying deeper water, and at still greater depths there would be a gradation toward, and finally into, true abysmal deposits.

It is immaterial whether the sediments are inorganic or organic so long as the comminution is such as to permit transportation in one or another of the three usual ways. Coral sand and silt are as susceptible to sloping sedimentation as siliceous or silicate sands and silts, and perhaps as frequently take on sloping attitudes. The depositional dips of corraline limestones are often of a pronounced order. Calcareous sands and silts from any organic source, foraminal, algous, and bacterial included, are susceptible of deposition on either topset or foreset slopes, and so beds of limestone or dolomite may alternate with other topset beds or foreset beds in normal sloping terranes.

The principles of stratification, and of stratigraphic interpretation, thus systematically embodied in the outward growth of the continental shelves, are likewise embodied in the growth of shelves from the borders toward the interiors of the smaller water-filled basins, whether these smaller basins arise from diastrophism or from any other source, and whether they are indentures of the borders of the continents or lie within them as mediterranean basins. In these smaller basins the shelves are usually narrower and the slopes are liable to be higher because the backward distribution of the sediments is less effective since the surface agitation and the circulatory currents are generally feebler, but this difference of slope is not inevitable nor universal.

There is this further difference, that in the intra-continental basins the land surrounds the water bodies and they are, in an areal sense, the minor elements, while the oceans surround the continents and, in an areal sense, are the major elements. In the intra-continental basins, the feeding areas are generally large compared with the depositional areas. The growth of the terraces is centripetal and their borders constantly diminish, while the growth of the circum-continental shelves is centrifugal and their borders constantly increase. While these are only features that have a quantitative bearing, they are worthy of passing notice because by far the larger part of the subaqueous strata that have been studied in detail by geologists are of the intra-continental or epicontinental order. The study of the circum-continental growths is a field to which less ample attention has been directed.

Before the foreset beds are left, some special features may well be considered but they are reserved for a later article.